End-to-End Data System Architecture for the Space Station Biological Research Project

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ABSTRACT

The Space Station Biological Research Project (SSBRP) is developing hardware for providing life sciences research capability on the International Space Station. This hardware includes several biological specimen habitats, habitat holding racks, a centrifuge and a glovebox. An SSBRP end to end data system architecture has been developed to allow command and control of the facility from the ground, either with crew assistance or autonomously. The system will be capable of handling commands, sensor data, and video from multiple cameras.

The data will traverse through several onboard and ground networks and processing entities including the SSBRP and Space Station onboard and ground data systems. A large number of onboard and ground entities of the data system are being developed by the Space Station Program, other NASA centers and the International Partners. The SSBRP part of the system which includes the habitats, holding racks, and the ground operations center, User Operations Facility (UOF) will be developed by a multitude of geographically distributed development organizations. The SSBRP has the responsibility to define the end to end data and communications systems to make the interfaces manageable and verifiable with multiple contractors with widely varying development constraints and schedules.

This paper provides an overview of the SSBRP end-to-end data system. Specifically, it describes the hardware, software and functional interactions of individual systems, and interface requirements among various entities of the end-to-end system. It includes some of the key challenges and the technical and programmatic approaches used by the project to handle those challenges.

1. INTRODUCTION

Key elements comprising the SSBRP end-to-end data system include specimen habitats, habitat holding racks, Centrifuge and Glovebox (host systems), Space Station Command and Data Handling System, Space Station Institutional ground data elements, the Ames UOF, and the Principal Science Investigators. The entire system will be developed over many years by many development organizations. The SSBRP developers include Boeing and NASDA developing the host systems, and at least six organizations developing the habitats. The Ames UOF is being developed in-house, where as the Principal Investigator facilities will be independently developed.

The distributed development environment made it necessary to utilize a systems engineering approaches in defining an end-to-end communications architecture so that interface issues can be proactively resolved. This architecture would help identify the requirements and contents for Interface Control Documents (ICDs) between different communicating entities in the system. SSBRP is coordinating the development of these interfaces and documents as a joint effort with the development organizations.

The following sections describe the software and communications architectures for telemetry, command and video sytems along with a mapping of the International Standards Organization (ISO) communication protocols for each element of the end-to-end system.

2. ARCHITECTURE DETAILS

Figure 1 shows the architecture and elements interacting in the end-to-end data and command systems.

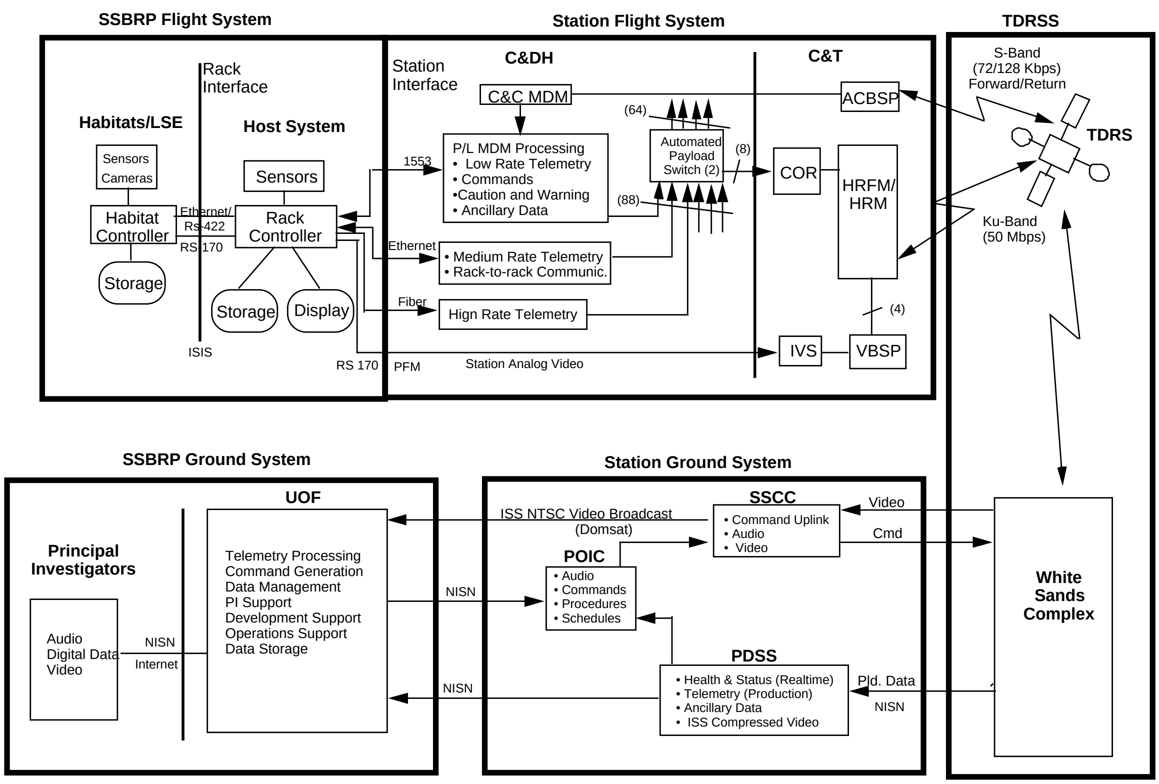

Figure 1. Elements of the End-to-End Data System Architecture

Habitats provide a controlled environment for a variety of biological specimens including plants and animals. Sensor data are digitized and included in application level packets (EXPRESS Headers [1])for transmission to the host systems. Packets include source identification, time, data type, packet number, and sensor data. Habitats keep their clocks updated by requesting Space Station time from the host systems.

Most of the automated actions are performed via a series of timed commands. Habitats will receive several days worth of timed commands as an uplink from ground. Execution of a command is immediately reported as a command log entry to the host system.

Habitats incorporate an internal analog video system, including cameras, and a switching mechanism operated via a set of timed commands. Video signals are routed to the host systems for storage and transmission to the ground.

Habitat interface requirements, excluding the application layer, have been documented by the SSBRP [2]. The application layer will be defined by the habitat developers.

Host Systems include Habitat Holding Racks, Centrifuge, and a Glovebox. They provide centralized resources to habitats for zero gravity maintenance in holding racks, controlled gravity in centrifuge, and science operations involving crew in the glovebox. Resources include power, thermal, fluids, air, data, command, and video systems.

Host systems receive commands from onboard and ground locations and forward them to habitats. Command sequences can be loaded in host systems to provide timed commands for several days. They perform first level command validation, and maintain a command log to incorporate status of all executed or rejected commands.

Telemetry data are received from all habitats via asynchronous messages. These data are stored as “First-In-First-Out” circular files for continually maintaining data received during the last 24 hours. Data downlink is scheduled based on availability of bandwidth via the Tracking and Data Relay Satellite System and Station resources. Telemetry storage and downlink is managed based on source ID, data generation time, and data type. Data sources include habitats, cameras, and sub-rack locations. Data types include health and status, low rate engineering and science, animal biotelemetry, digital video, and several operational data types such as command logs and asynchronous events. A telemetry configuration table is maintained for each data type. It allows transmission of data via one of the three communication links provided by the Station: MIL-STD-1553B for low rate data, Ethernet 10 Base-T for medium rate data, and a Fiber optic point to point link for high rate data. All data packets received from the habitats and sub-host locations are further encapsulated into Consultative Committee for Space Data Systems (CCSDS)[3] packets before transmission to the Space Station.

Host systems also incorporate video switching, routing and compression capability. Analog video received from habitats is multiplexed to four output channels: display, routing to the station, and simultaneous compression of two channels. Motion Pictures Expert Group (MPEG-2) standard is being considered for video compression. Digital video data will be stored and telemetered along with other science and engineering data.

Host systems include an attached laptop computer for video and data display, and command capability for the onboard crew.

Space Station Data System provides telemetry and command interfaces, and limited computing resources to payloads [4]. The Payload Multiplexer/DeMultiplexer (PL MDM) collects and forwards all commands to host locations via the MIL-STD-1553B interface. It also provides ancillary data from other Station sensors and collects Health and Status data from every host system at regular intervals. Total bandwidth for all Station users including overheads is 1 Mbps.

Two Ethernet Local Area Networks are provided: one for rack-to- rack communications and the other for telemetry. Total bandwidth available on this link is 10 Mbps including overheads. A high rate fiber link connects each rack to a switch for multiplexing up to eighth inputs using a high rate frame multiplexer. Although the high rate links are capable of handling up to 100 Mbps throughput, the space to ground link is limited to a net 43.2 Mbps.

Tracking and Data Relay Satellite System provides space to ground communications via two geosynchronous satellites. Command and data uplinks are performed via S-band communications at 57 Kbps. Data downlinks use Ku-band communications at 43.2 Mbps. TDRSS limitations include a zone of exclusion once every orbit and occultation due to structural blockage of the antenna line of sight. This communications outage impacts the design, planning, and operation of the SSBRP host systems data recording and playback.

Space Station Ground Data Systems include the Payload Operations and Integration Center (POIC) which provides command and control capability to Station payloads, and the Payload Data Services System (PDSS) which provides telemetry support to users.

The PDSS will receive, process, store, and distribute ISS Ku-band data to the user community including the SSBRP UOF using the NASA Integrated Services Network (NISN). The PDSS will also receive and store ground ancillary data from the Payload Operations Integration Center (POIC) and will distribute it to the user community in near-real-time. In addition, the PDSS will provide payload health and status data (a subset of payload data) and core systems data to the POIC.

The POIC provides for the aggregation and forwarding of all Space Station Payload commands and file uplinks. It will receive CCSDS Command Packets from the Ames UOF and forward these Command Packets to the Space Station Control Center (SSCC) for uplink to the ISS.

User Operations Facility located at NASA Ames Research Center, will provide the capability to initiate commands by the UOF operators or Principal Investigators as well as receive, process, store, and distribute SSBRP telemetry data [5].

UOF Operators will generate commands, timed commands, and command sequences for operation of the onboard systems. UOF will validate commands for format, structure, tolerances, and other constraints. Validated commands will be encapsulated within CCSDS packets and forwarded to the POIC for uplink to the ISS. Status of command execution will be monitored using Command Acceptance Responses and information available via the POIC.

The UOF will receive telemetry data from the PDSS via NISN. UOF front-end processing will route a copy of all real-time (properly sequenced) payload data for initial processing and immediate distribution to the SSBRP operations team. This portion of the telemetry data will be used by operations personnel to perform monitoring and control of SSBRP experiments and equipment. The UOF front-end processing will also route a second copy of all received telemetry data (sequenced or not - including all playback telemetry data) to a relational database management system for storage.

UOF telemetry data will be extracted from the Enhanced HOSC System [6](EHS)/CCSDS packets and stored using a relational database management system. Telemetry data generation time will be used as the primary database relationship, thereby essentially reordering telemetry data during storage. Digital video (stored in compressed form) will be stored as virtual video clips and accessed through references in the relational database.

The time data was generated will be used as the primary selection pointer for all data parameters. The relational database structure will be transparent to data users.
Telemetry data will be accessible to internal and external data users on-line for 120 days from data generation date. During this on-line period the data is available to both internal and external users. Data will be considered lost if not accessed during the 120 day period.

The UOF will provide a web server for distribution of telemetry data to the remote Principle Investigators on a slightly delayed basis. A JAVA enabled browser will “go and get the data required” in the display or file format needed. The requests and data distribution will be an interactive process allowing both animated data and video streams to be transported to the remote user's facility.

Remote Principal Investigator (PI) Facilities form one end of the SSBRP end-to-end data system. PIs will be geographically distributed and will be the primary users of the science data acquired by the SSBRP data system.

Remote PIs will initiate command requests via analog voice circuit or digital data transmission. Digital data transmission includes secure e-mail, browser/server transactions, and file transfer. Generally, PIs cannot command the habitats directly because specimens and habitats are typically shared between multiple PI and request for commands have to be coordinated between them during real-time planning or re-planning exercises. In some cases, direct commands of experiment unique equipment may be available pending resolution of security issues.

PIs at their remote facility will have access to both the real-time and stored data using web browser/server technology. Access to the telemetry data is again restricted by data sensitivity and proprietary data restrictions. Transportation of this telemetry data over an open network may require encryption for privacy. At a minimum, the remote Principle Investigator will be authenticated and all password transmissions encrypted.

Remote PIs will receive their telemetry data from the NASA Science Internet element of NISN or the Internet.

3. Interface Requirements

The heterogeneity of the communicating elements in the command and data flow architecture is demonstrated in Figure 2. The Figure shows a mapping of the International Standards Organization (ISO) communication protocol layers for the significant elements involved. The mapping was used to explore to-be-defined or unidentified protocols, and to lay a basis for outlining Interface Control Documents between various entities of the system.

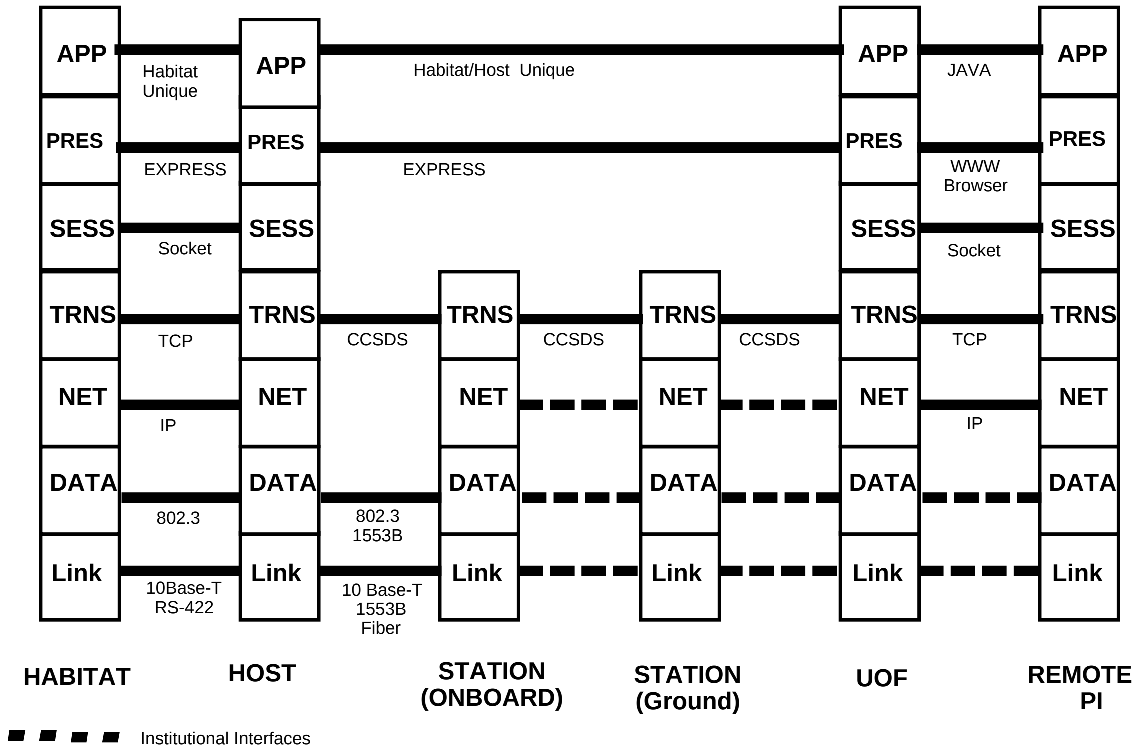

Figure 2. Inter-Element Communications Interfaces

4. Benefits Achieved

A proactive systems engineering approach in analyzing the SSBRP end-to-end data system provided a great advantage in delineating functional requirements of individual elements. Before this analysis, there was no clear demarcation between data and command functions to be performed by the habitats, host systems, and ground systems. Several functions were duplicated across the board or not available at all. A clear understanding of the Interface requirements was achieved. Also, a basis was established for test and verification of communications interfaces.

5. References

1. EXPRESS Software Interface Control Document, D683-43525-1, February 1998
2. SSBRP Intra Facility Interface Specification, ARC/CF-11514, March 1998
3. CCSDS Recommendations for Space Data Systems Standards, Advanced Orbiting Systems, Networks and Data Links: Architectural Specification, CCSDS 701.0-B-2, Blue Book, November 1992.
4. Pressurized Payloads Interface Requirements Document, SSP 57000,
5. Communication & Data System Requirements Document, ARC/CF-16301
6. EHS Protocol Requirements, HOSC-RQMT-2237, July 1994